# Climate Proof Fresh Ground Water Supply: an adaptive water management strategy with regional impact

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**Resumen**

El sistema hidrológico en los Países Bajos está en riesgo. El cambio climático, la subida del nivel del mar, la subsidencia de tierras y las presiones antropogénicas dificultarán disponer de los actuales recursos de agua dulce en un futuro. La situación se hará aún más insostenible en condiciones de sequía. Por esta razón el tema de suministro de agua dulce es una de las prioridades más importante en el Programa Delta y en el Plan Nacional de Agua. Actualmente se están desarrollando estrategias de adaptación dentro de estos programas. En este artículo presentamos una de las estrategias de adaptación: la suministración de agua dulce subterránea a prueba del cambio climático para el delta del Suroeste; un delta en los Países Bajos que se encuentra casi en su totalidad bajo el nivel del mar y en condiciones salinas. Se han iniciado dos proyectos piloto: 1. La infiltración de agua dulce en loma fluvial arenosa a través de sistemas de drenaje, almacenamiento y recuperación, y 2. La optimización del volumen de agua dulce en lentejones someros de agua de lluvia con la ayuda de sistemas de drenaje situados a una cierta profundidad. Agricultores, institutos de investigación y gobiernos locales cooperan para que este proyecto sea un éxito. Con la combinación de campañas de monitoreo (colección de datos y métodos geofísicos) y de modelos numéricos de flujo de densidad variable y transporte, la eficacia de las medidas de adaptación se evaluará, y si es interesante, se implementará en otras regiones.

**Palabras clave : Suministro de agua dulce, salinización, agua subterránea, cambio climático, gestión del agua**

**Abstract**

The Water System in the Netherlands is at risk. Climate change, sea level rise, land subsidence and anthropogenic stresses will very likely make the present service level of fresh water availability impossible. This is especially pressing under dry (summer) conditions. For this reason, the theme fresh water supply is a top priority in the Delta Programme and the National Water Plan. National adaptive strategies are being developed now. In this paper, we will discuss one adaptive strategy: Climate Proof Fresh Ground Water Supply for the Southwestern Delta, a low-lying saline environment in The Netherlands. Two showcases are set up: a. Infiltration via drainage, storage and recovery of freshwater in a sandy creek ridge, and b. Optimizing the freshwater volume in shallow rainwater lenses by different types of deep drains. Farmers, knowledge institutes and local governments work together to make it a success. By combining monitoring campaigns (data-collection and geophysical methods) and numerical modelling of variable-density groundwater flow and coupled solute transport, the efficiency of these measures will be evaluated, and if worthwhile, implemented in other regions.

**Key words: fresh water supply, salinisation, groundwater, climate change, water management, climate change**

## 1. INTRODUCTION

Water management in the Dutch coastal zone is at risk. Salt water wedges intrude river and estuarine branches, leading to external salinisation of the surface water system. At the same time, internal salinisation of the groundwater system is continuously taking place; this process was initiated some centuries ago when we started to drain our land (fig. 1). Both types of salinisation processes threaten agriculture, drinking water supply and nature. On top, the following future physical drivers will jeopardize our water system even more (fig. 2):

- climate change (including sea level rise),
- land subsidence (up to 1 m per century in the peat areas),

- necessary operational water management strategies (e.g. adapting water level).

For instance, modelling results of salt water intrusion in The Netherlands show that the water system significantly becomes more saline these coming 100 years (fig. 3). Water courses need to be flushed more intensively if water boards want to maintain the present water quality in the surface water system (Oude Essink *et al*., 2010; Oude Essink, 2011).

To make The Netherlands Climate Proof for the coming century, fresh water supply is (next to safety against flooding) one of the top priorities in the Delta Programme and the Dutch National Water Plan. National adaptive strategies are being developed to make this happen, supported by research programs.

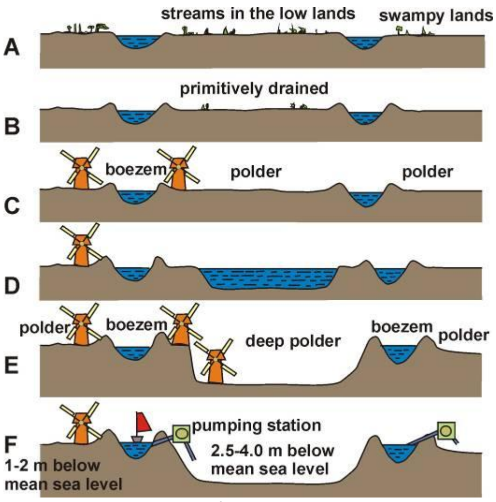


Fig. 1: Development of the Dutch polder region (Wesseling, 1980). A. Before occupation of man; B. After damming of the streams at their mouths and their embankment, separation of 'boezem' and 'polder' by small dikes; C. Subsidence of the peaty polder soils and pumping of windmills; D. Digging out of some polders for peat making; E. After draining of the lake originating from peat making; F. Present situation.

## 2. CLIMATE PROOF FRESH WATER SUPPLY

*Climate Proof Fresh Water Supply* is such a research program. One of the aims of this Knowledge for Climate project is to develop robust, flexible and long-term solutions that can contribute to successful water management strategies in our changing Dutch Delta (fig. 4). Several PhD's are researching the effects of Climate Change on ecology, hydrology and hydrogeology (such as salt damage to crops, volumes of freshwater lenses, etc.). In addition, the robustness and flexibility of the water system in response to climate change is analyzed, and policy tipping points[1] in present water management are identified.

[1] A policy tipping point is a point where the magnitude of chance is such that the current magnitude strategy can no longer meets its objective. Themes are coastal defence, salinisation, nature, accessibility harbour Rotterdam.

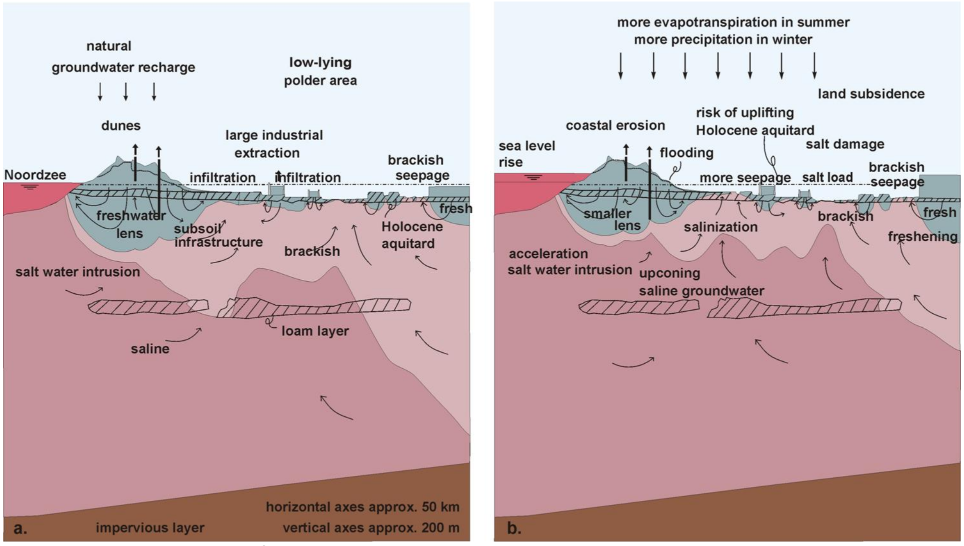

Fig. 2: a. Schematization of the groundwater system in the Dutch deltaic area; b. Possible processes that occur in case of climate and global change.

Main questions of this project are:

- how will the spatiotemporal patterns in the fresh water availability in ground- and surface water in coastal lowland regions change due to climate change;
- how can effective regional adaptation strategies be implemented to sustain present water-dependent functions in the future?
- what is the potential of measures to either increase water availability or decrease water demand?
- to what extent do these strategies contribute to a national solution for a climate proof freshwater supply?

We will investigate whether or not a combination of local to sub-regional adaptive strategies (worked out in showcases) exists to make regional fresh water supply possible in the future.

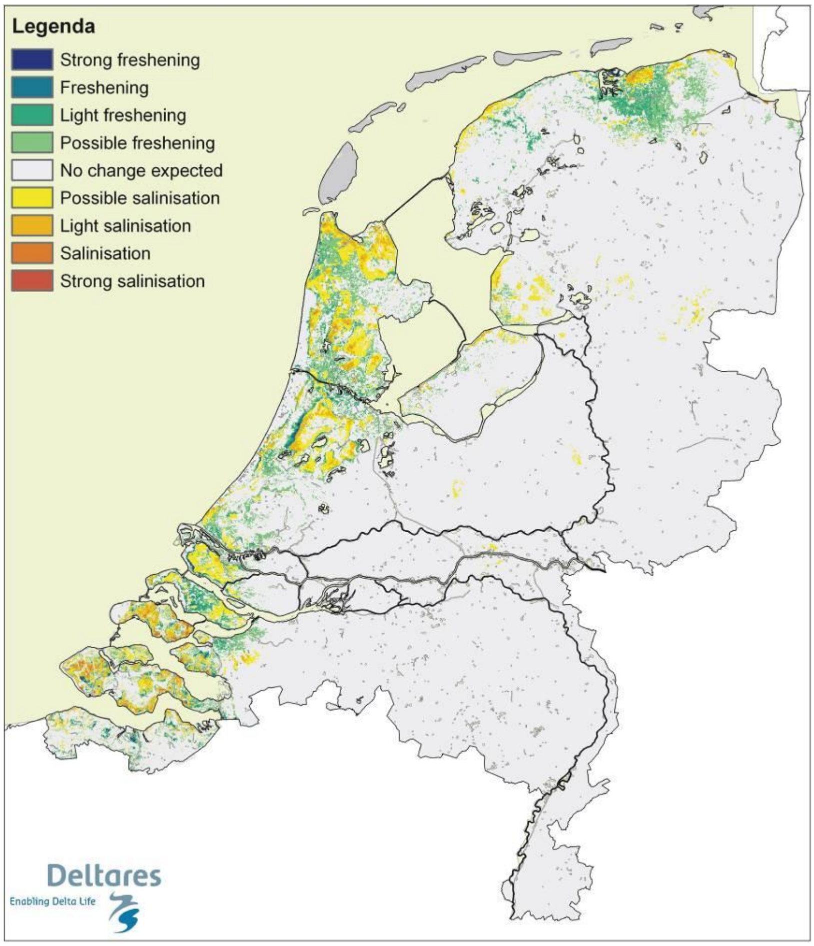


Fig. 3: Salinisation and freshening at the top of the groundwater system in 2100 AD relative to 2010 AD due to autonomous development (caused by past lowering in polder water levels).

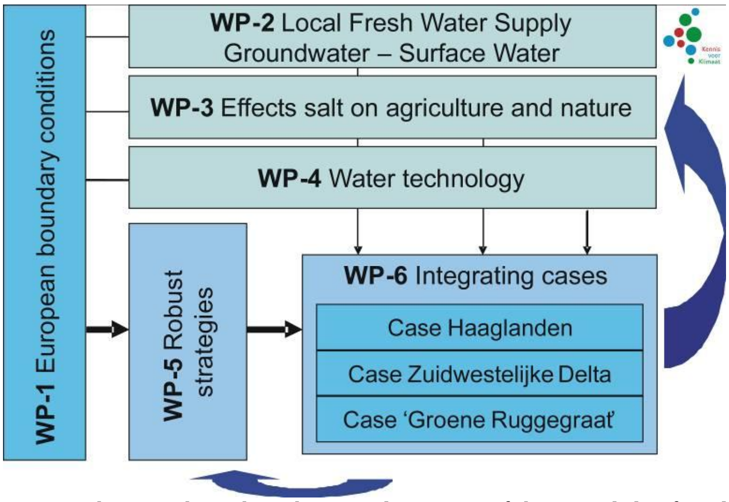


Fig. 4: Scheme with work packages and activities of the Knowledge for Climate project *Climate Proof Fresh Water Supply*.

## 3. METHODOLOGY

The following (straightforward) steps towards a setting with a robust fresh water supply can be identified:

(a) better understand the present water system,
(b) assess the impact of future climate and anthropogenic stresses to (ground)water,
(c) communicate and cooperate with (local) stakeholders, like farmers and water board,
(d) come up with and implement feasible, robust and flexible strategies for future water management: start with showcases and upscale to larger regions.

In this article, we focus on the local groundwater system, viz. the shallow freshwater lens (fig. 5) and the medium scale freshwater lens in sandy creeks. We strongly believe that the third (vertical) dimension of this groundwater system can make a difference: storing the surplus of fresh water in the subsoil in the wet winter period and use this water during dry summer periods is promising.

Numerical models of the fresh-salt groundwater system on local to sub-regional scale are constructed and monitoring campaigns are executed to show the efficiency and thus to increase the success of the strategies. Stakeholder participation processes (inform, communicate with and learn from local/regional policy makers, farmers, drainage companies) will also increase the implementation of possible successful solutions in the field.

The location of the showcases is in our Southwestern Delta, a low-lying saline environment in the Netherlands with high climate proof fresh groundwater supply potentials and where stakeholders strongly support innovations in water issues.

## 4. BETTER UNDERSTAND THE PRESENT WATER SYSTEM: THE FRESHWATER LENS

During the past years, extensive research has been executed, from fieldwork for the collection of geophysical, hydrological and geohydrological data to better understand the behaviour of freshwater lenses. In addition, numerical modelling is executed to predict the impact of sea level rise, climate change and measurements to adapt to and mitigate the salinisation (Oude Essink *et al.*, 2009; De Louw *et al.*,2011; Eeman *et al*,, *2011*).

In many Dutch low-lying areas, saline groundwater is often encountered at shallow depths (< 10-15 m). Precipitation surplus lead to the forming of rainwater lenses on top of saline groundwater. The thickness throughout the seasons may have major implications for these freshwater lenses. On top of the climate effects of rainwater lenses depends on factors like recharge, seepage flux, salinity, drainage characteristics. They vary in thickness from > 50 m in dune areas, 5 to 20 m in fossil sandy creeks to < 1 to 2 m in agricultural parcels in polder areas with prominent saline. The fresh water availability for agricultural purposes depends on these shallow and medium freshwater lenses.

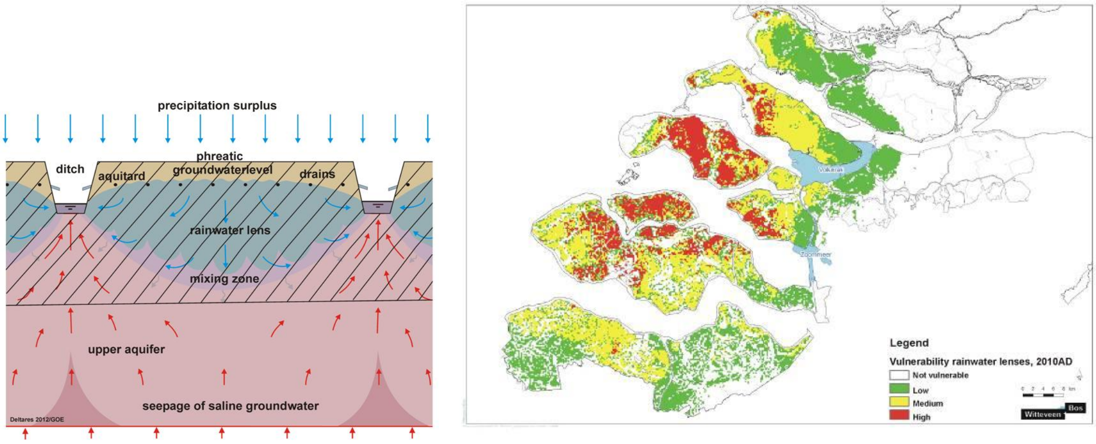


Fig. 5: a. Conceptual visualisation of a shallow freshwater lens on top of saline groundwater seepage; b. Map of vulnerability of shallow freshwater lenses on salt damage to crops.

## 5. ASSESS IMPACT OF FUTURE CLIMATE

The next step is to answer whether or not this vulnerable shallow fresh groundwater system is sensitive to climate change, sea level rise, land subsidence and possible anthropogenic pressure (such as intensive groundwater extraction) (see also fig. 5b). Changes in precipitation and evaporation both in quantity and seasonal distribution as well as sea level rise will accelerate saline seepage in the lower lying areas. Moreover, the freshwater lenses will especially be vulnerable during summer time, when both precipitation deficits and groundwater extractions for agricultural purposes are the largest. Fig. 6 shows an example of the effect on fresh groundwater volumes in a freshwater lens under the so-called W+ climate change scenario: the shallow freshwater lens will disappear and the creek ridge freshwater lens will be minimized. However, it is still unclear how these fresh water lenses in the whole region exactly react under new climate, sea level and socio-economical conditions, and how water management in these low-lying areas will anticipate.

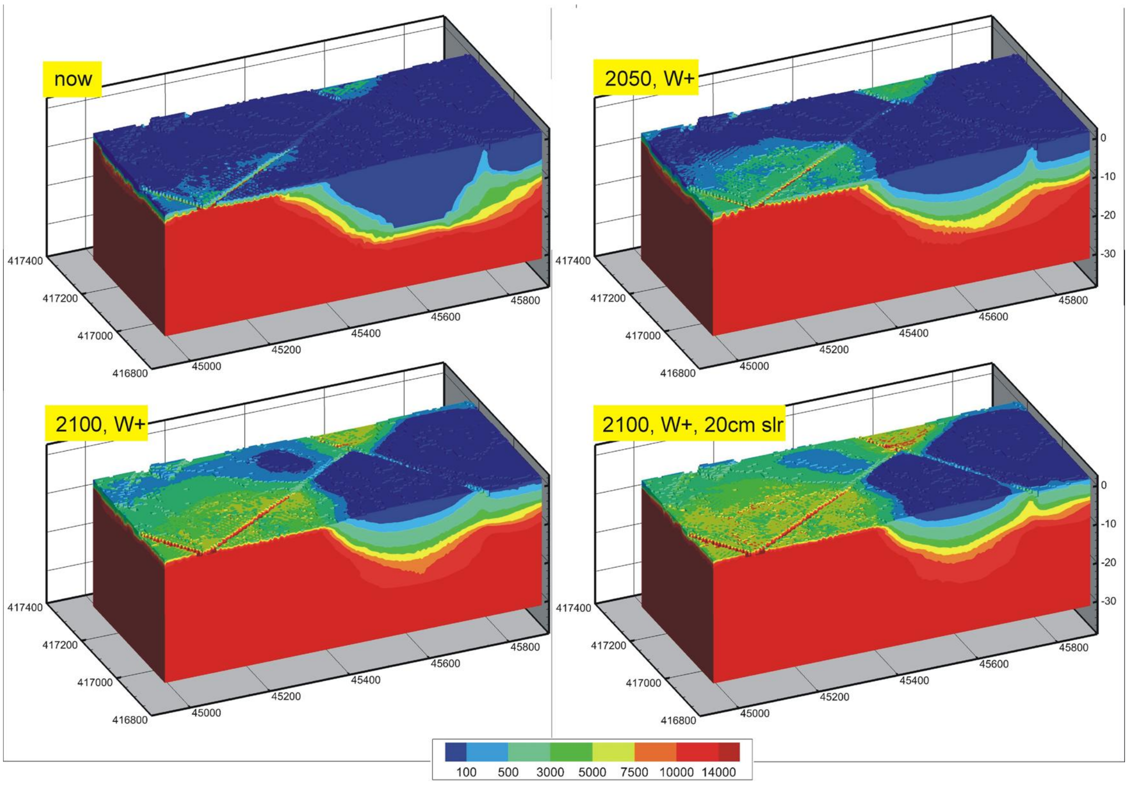

Fig. 6: Vulnerability of a freshwater lens to climate change and sea level rise (under W+ climate scenario): green means that concentration in top water system is so high that salt damage to crops is likely to occur. Upconing saline groundwater from deeper parts of the system towards the surface water ditches can clearly be seen.

## 6. COMMUNICATE AND COOPERATE WITH (LOCAL) STAKEHOLDERS

Pretty straightforward, but communication and cooperation with local stakeholders will make a difference! Site-specific knowledge such as on drainage and ditch characteristics, soil conditions and crop production in the field can make a measure successful. When correctly instructed, they can even help in data collection during monitoring campaigns.


Fig. 7: Communication with stakeholders: their local knowledge and eagerness to adapt to a changing environment is essential to make measures for climate proof fresh water supply, suggested by hydrogeologists (photos by courtesy of Van Baaren, Rentmeester and Van der Hoek).

7. COME UP WITH FEASIBLE, ROBUST AND FLEXIBLE STRATEGIES

We will work out two showcases (fig. 8) this coming year:

1. Infiltration via drainage, storage and recovery of freshwater in sandy creek ridges in a saline environment (ASR), utilizing the potential of the creek ridge for water storage, with the focus on infiltration of surface water via drains.
2. Optimizing the freshwater volume in shallow rainwater lenses by different types of (deep) drains.

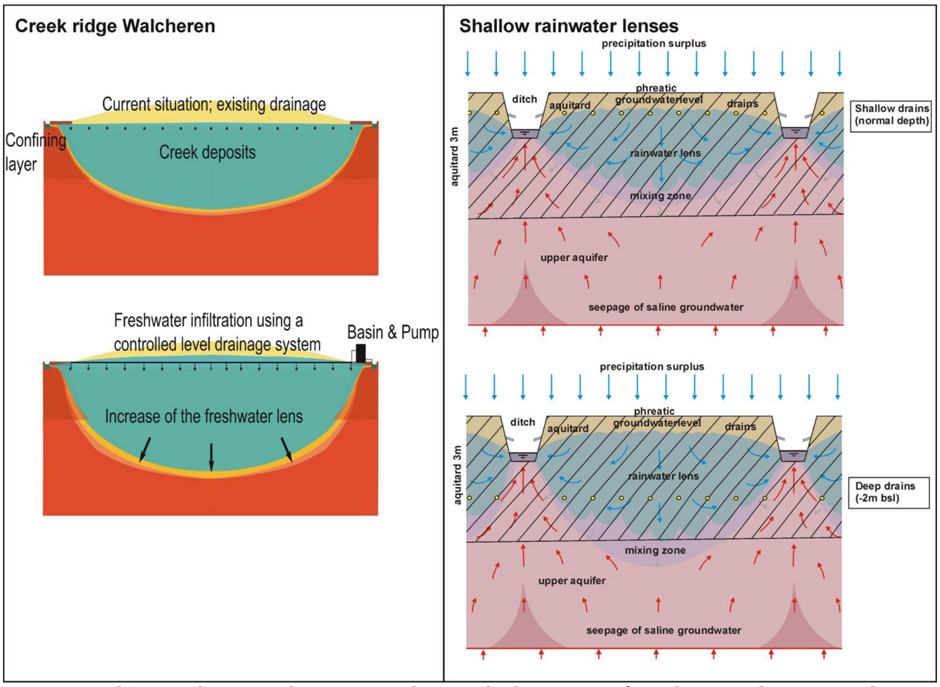


Fig. 8: Local (ground)water solutions to make Local Climate Proof Fresh Groundwater Supply possible.

This coming year, we will use monitoring campaigns and modelling exercises to show the efficiency of these measures.

8. CONCLUSIONS

In the Southwestern Delta, a low-lying saline environment in The Netherlands, there is a momentum to implement adaptive strategies based on Local Climate Proof Fresh Groundwater Supply (fig. 9). The base idea is to store the surplus of fresh water in the subsoil in the wet winter period and to use this water during dry summer periods is promising. By increasing the freshwater volume in the subsoil, more fresh water is stored for times of water deficit.

Farmers, knowledge institutes and local governments work together to make the showcases a success. By combining monitoring campaigns (data-collection and geophysical methods) and numerical modelling of variable-density groundwater flow and coupled solute transport, the efficiency of these measures can be evaluated.

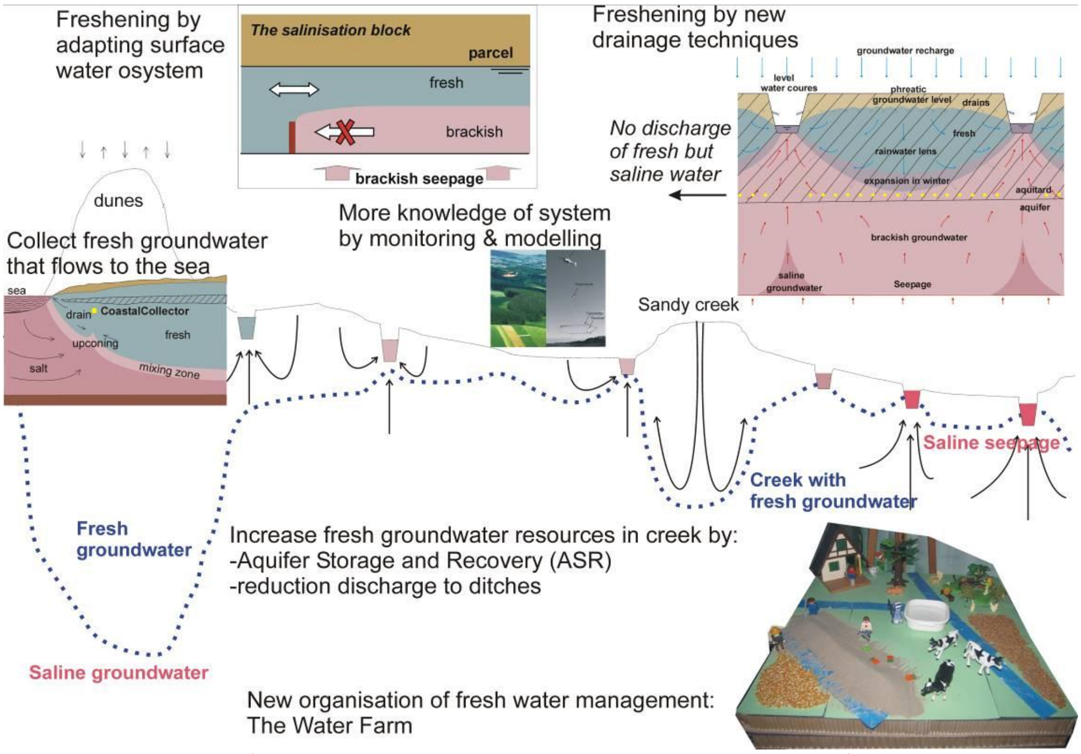


Fig. 9: A combination of local (ground)water solutions to make Local Climate Proof Fresh Groundwater Supply possible.

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